A POSSIBLE LIMITATION OF THE PRECISION OF h/e^2 DETERMINED FROM THE QUANTUM HALL EFFECT

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Random peaked structures have been observed both in the Hall and transverse resistivities traced against the gate voltage for Si-MOSFETs. The amplitude amounts to 30% of the transverse resistivity when the electron concentration is 5×10^{11} cm^{-2}, at 12mK. These observations suggest that a limitation of the precision would exist for the determination of h/e^2 based on the quantum Hall effect.

The quantization of the Hall conductivity in units of e^2/h in two dimensional electron systems under strong magnetic fields [1,2] has recently generated much interest since the phenomena provides potentially an atomic resistance standard and/or a new method to determine the fine structure constant $\alpha = e^2/\hbar c$. The essential part of the phenomena was predicted theoretically in 1975 [3]. After the first precision measurement with Si-MOSFETs [1], many theoretical works have been presented, in which is discussed that the unit of quantization is exactly e^2/h in various situations [4]. According to the experiments with improved accuracy, the Hall resistivity is integral fractions of a constant in precision better than two parts in 10^7 and the value of the constant coincides with the known value of h/e^2 within the uncertainty of the magnitude of the resistance unit 1 Ohm [5]. The values of the Hall resistivity corresponding to $h/4e^2$ obtained from the measurements with GaAs-AlGaAs heterostructures [6] coincide with those with Si-MOSFETs within the experimental uncertainty less than 1 part in 10^6. Up to the present, no theoretical suggestion has been obtained about the ultimate accuracy of the quantization in the experimentally available situations, eg., finite temperature and magnetic fields, finite sample width and length, etc.

In the present note we would like to discuss a possible limit of accuracy determined from the characteristics of devices and the experimental conditions on the basis of the result of measurements on Si-MOSFETs. The maximum mobility of the samples was 1.2×10^4 $cm^2/V \cdot s$ at 4.2 K. The Hall and transverse resistivities were measured at temperatures ranging from 4.2 K to 12 mK under the magnetic inductions up to 12 T. The channel current was changed from 10^{-5} A to 10^{-9} A, which corresponds to the electric field applied to the sample from 6 V/cm to 6×10^{-4} V/cm at the $h/4e^2$ Hall resistance plateau.

Fig. 1 shows an example of the recorder traces of Hall resistivity ρ_{xy} and transverse resistivity ρ_{xx} vs. gate voltage V_g. As is seen in the figure, random peaked structures are superposed both on ρ_{xy} and ρ_{xx} vs. V_g curves. The structure is seen on the $h/2e^2$ plateau, but not clearly seen on the $h/3e^2$ and $h/4e^2$ plateaus

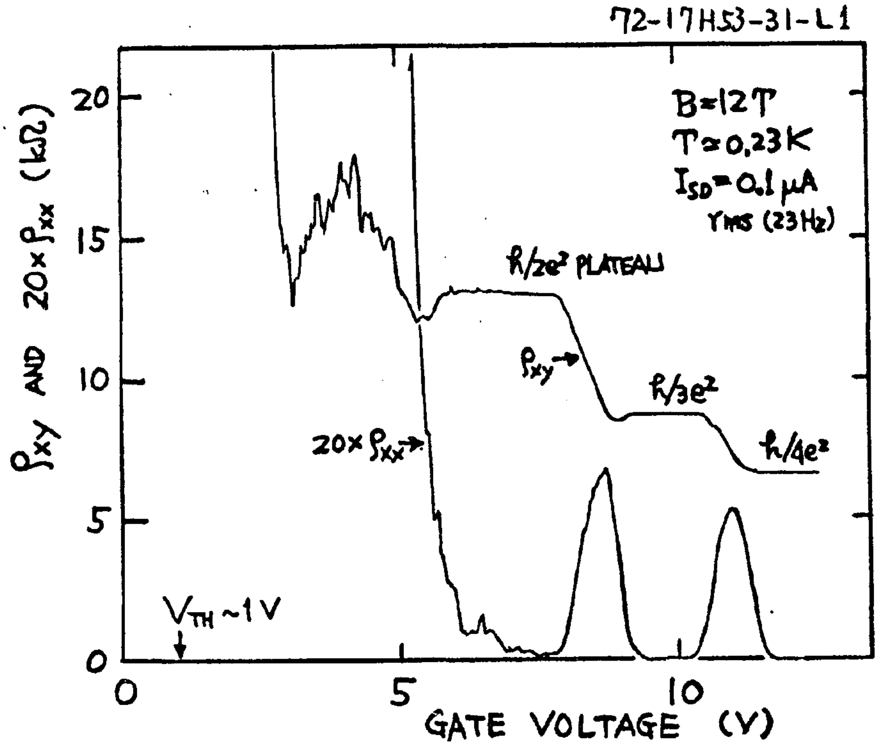

Fig. 1.
Hall and transverse resistivities as functions of gate voltage. The sample is 600 μm in length and 100 μm in width.

in this recorder chart scale. The structures are highly reproducible within a sample. The position in gate voltage of the peaks and dips is nearly independent of temperature and values of channel current. The amplitude of the random structure increases as the temperature is lowered and also as the channel current is decreased. The amplitude decreases exponentially with an increase of the gate voltage, and is roughly independent of the magnetic field. The amplitude amounts to 30 % of the transverse resistivity at the gate voltage $V_g \approx 5$ V (corresponding surface electron concentration is 5×10^{11} cm^{-2}), at a channel current $I_{SD} \approx 10^{-8}$ A and at the lowest temperatures, for example. The structures are different from sample to sample, although the amplitudes and periods in gate voltage look alike as functions of the gate voltage for the samples on the same chip. The structures are similar to those found in the differential conductance reported previously [7], but are far larger in amplitudes.

The effect of the random peaked structure is not appreciable on the $h/4e^2$, $h/8e^2$ and $h/12e^2$ plateaus up to the present resolution of the measurement, $\approx 10^{-7}$, under the condition of the precision measurement [5], i.e., $I_{SD} \approx 10$ μA dc, $T \approx 0.5$ K, $B \approx 10.5 \sim 12$ T, $V_g > 10.5$ V for the Si-MOSFETs with high mobility. However the effect would be apparent when the resolution of the measurement is improved enough, say to 10^{-8} or better. In that case the random structure is supposed to determine the limit of precision. The similar structure has been observed also in GaAs-AlGaAs heterostructures [8].

Fig. 2 shows the $h/4e^2$ plateau for a GaAs-AlGaAs sample measured recently at the NBS [9]. The error bars accompanied the data denote one standard deviation of random uncertainty $\pm 1\sigma$ of each measurement. The Hall resistance value in the

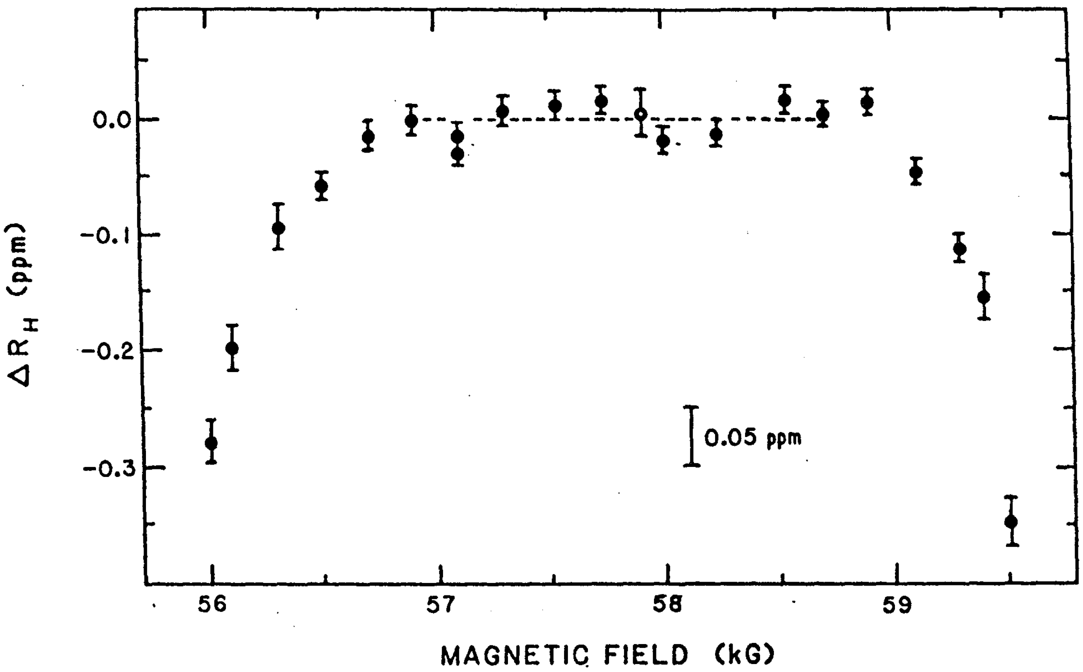

Fig. 2. The $h/4e^2$ plateau for the sample GaAs(7). The data points are plotted as deviations of Hall resistance in ppm from the flat region of the plateau. $T = 1.5$ K, $I_{SD} = 25$ μA (Reproduced from NBS data [9]).

plateau region looks varying with the amplitude of about 2.5σ p-p, although it is not clear whether the variation is only the statistical fluctuation.

At present further experiment with better resolution and/or experiment down to very low (≈ 10 mK) temperatures with present resolution would be needed to derive a conclusion to the problem whether the random structure gives a limit of precision of the h/e^2 value obtained from the quantum Hall effect.

References:

[1] K. von Klitzing, G. Dorda and M. Pepper: Phys. Rev. Lett. 45 (1980) 494.

[2] S. Kawaji and J. Wakabayashi: "Physics in High Magnetic Fields" ed. by S. Chikazumi and N. Miura (Springer, Berlin, 1981) p. 284.

[3] T. Ando, Y. Matsumoto and Y. Uemura: J. Phys. Soc. Jpn. 39 (1975) 279.

[4] H. Aoki and T. Ando: Solid State Commun. 38 (1981) 1079; R. B. Laughlin: Phys. Rev. B23 (1981) 5632, for representative examples.

[5] K. Yoshihiro, J. Kinoshita, K. Inagaki, C. Yamanouchi, J. Moriyama and S. Kawaji: J. Phys. Soc. Jpn. 51 (1982) 5.

[6] D. C. Tsui, A. C. Gossard, B. F. Field, M. E. Cage and R. F. Dziuba: Phys. Rev. Lett. 48 (1982) 3.

[7] R. J. Tidey, R. A. Stradling and M. Pepper: J. Phys. C7 (1974) L353; T. Cole, A. A. Lakhani and P. J. Stiles: Surf. Sci. 58 (1976) 56.

[8] K. von Klitzing: Private Communication.

[9] B. N. Taylor: Private Communication.